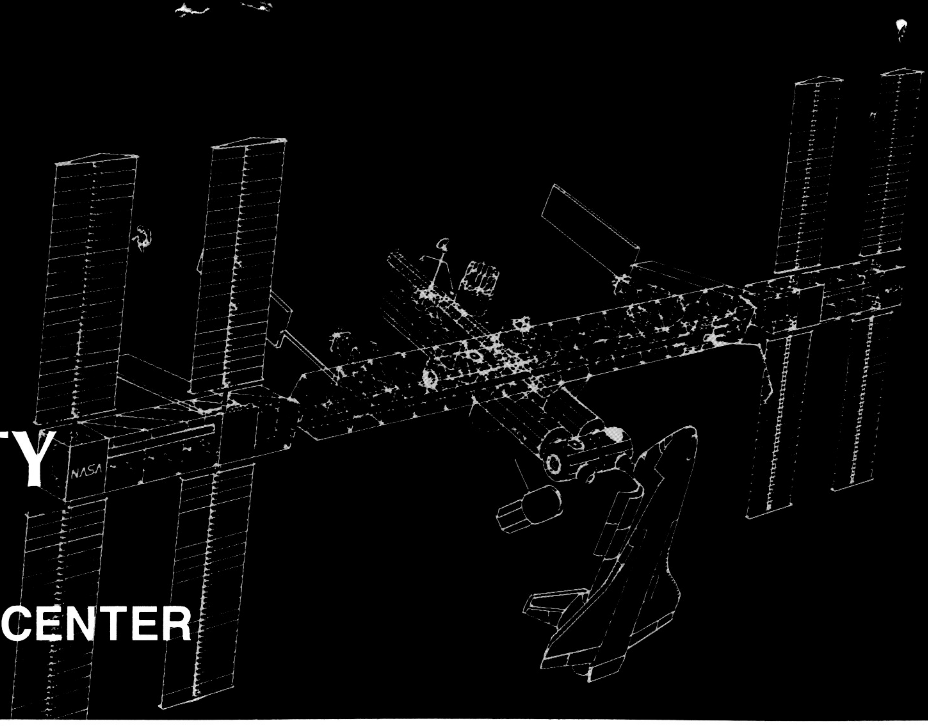
POWER SYSTEMS FACILITY



LEWIS RESEARCH CENTER

(NASA-TM-101447) POWER SYSTEMS FACILITY N89-14247
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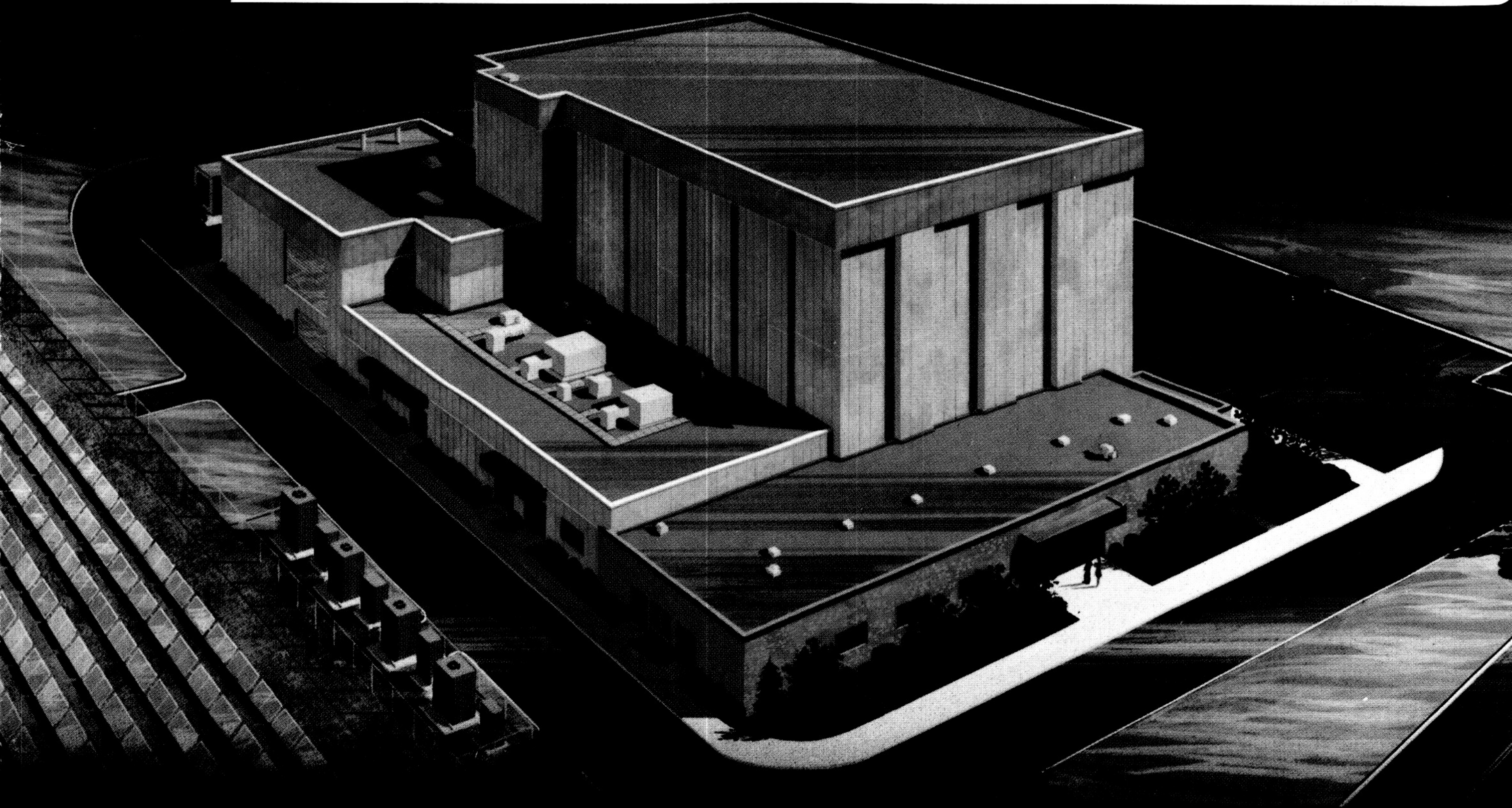


National Aeronautics and
Space Administration

FOREWORD

In 1984, the President directed NASA to undertake the development of Space Station Freedom, the next step in a broad-based U.S. civil space program to develop space-flight capabilities and to exploit space for scientific, technological, and commercial purposes. Under that direction, NASA awarded contracts in 1985 for concept definition and preliminary design studies. Those studies have been completed and the Space Station Freedom Program is now in the final design and development phase, leading to a permanently manned space station that will be operational in the mid-1990's.

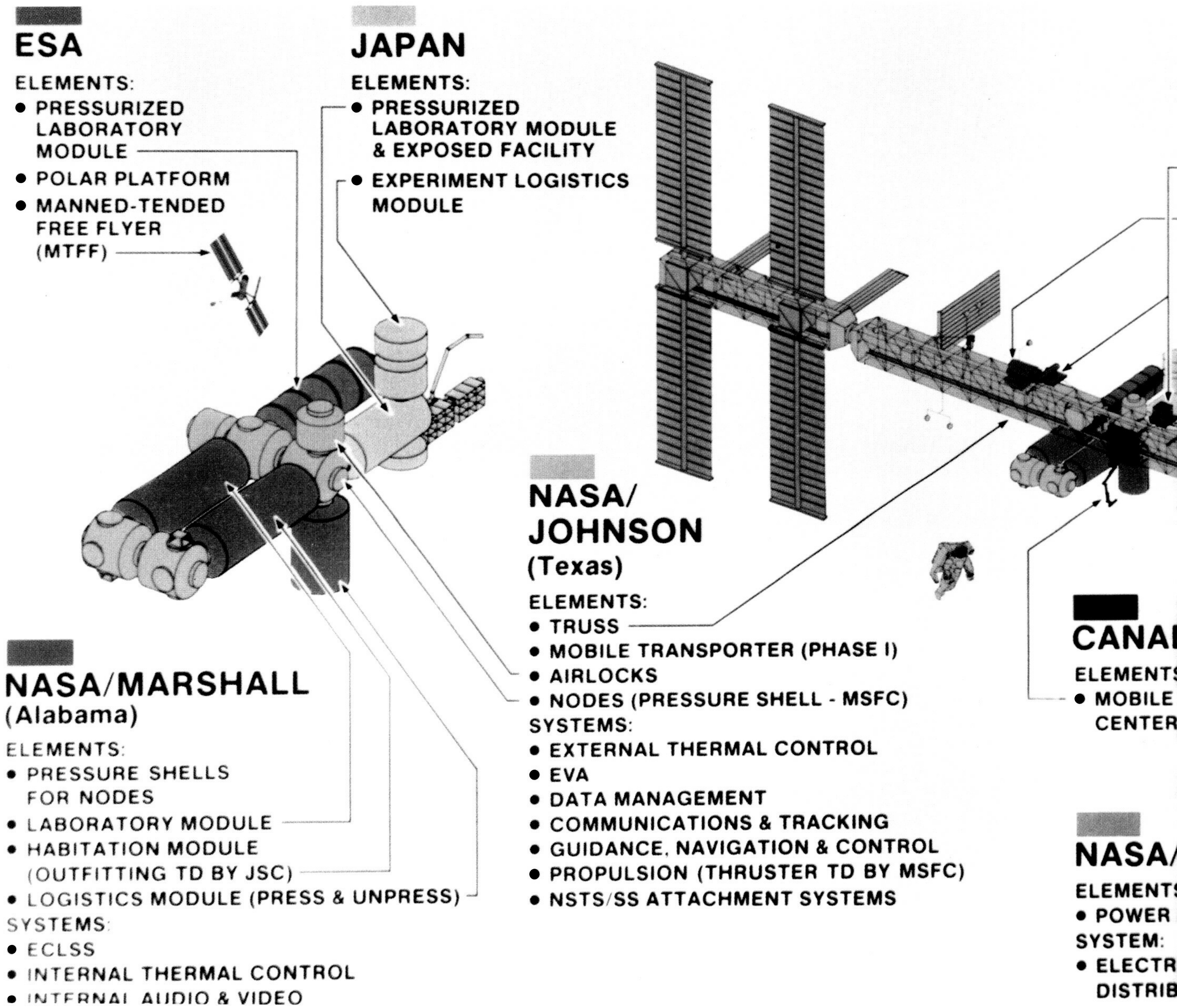
Here at the Lewis Research Center, with Rocketdyne, we are developing and building the S.S. Freedom electrical power system (EPS) hardware and software.

A major portion of the EPS will be tested at Lewis. The Power Systems Facility (PSF) was specifically designed for testing the EPS and uses the latest in testing equipment.

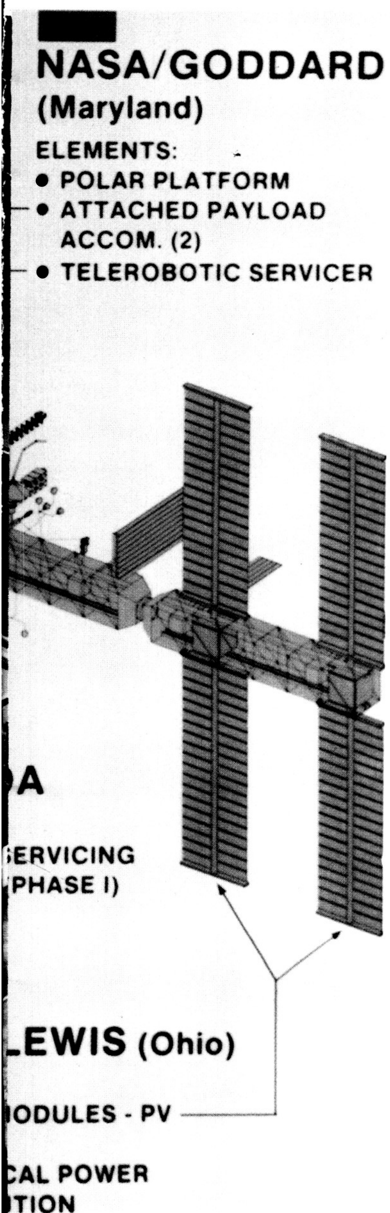
Freedom will be the stepping stone into the future. We at Lewis are proud to provide crucial support to this effort.

Ronald L. Thomas

Ronald L. Thomas
Director
Space Station Freedom Directorate



Initial configuration of Freedom

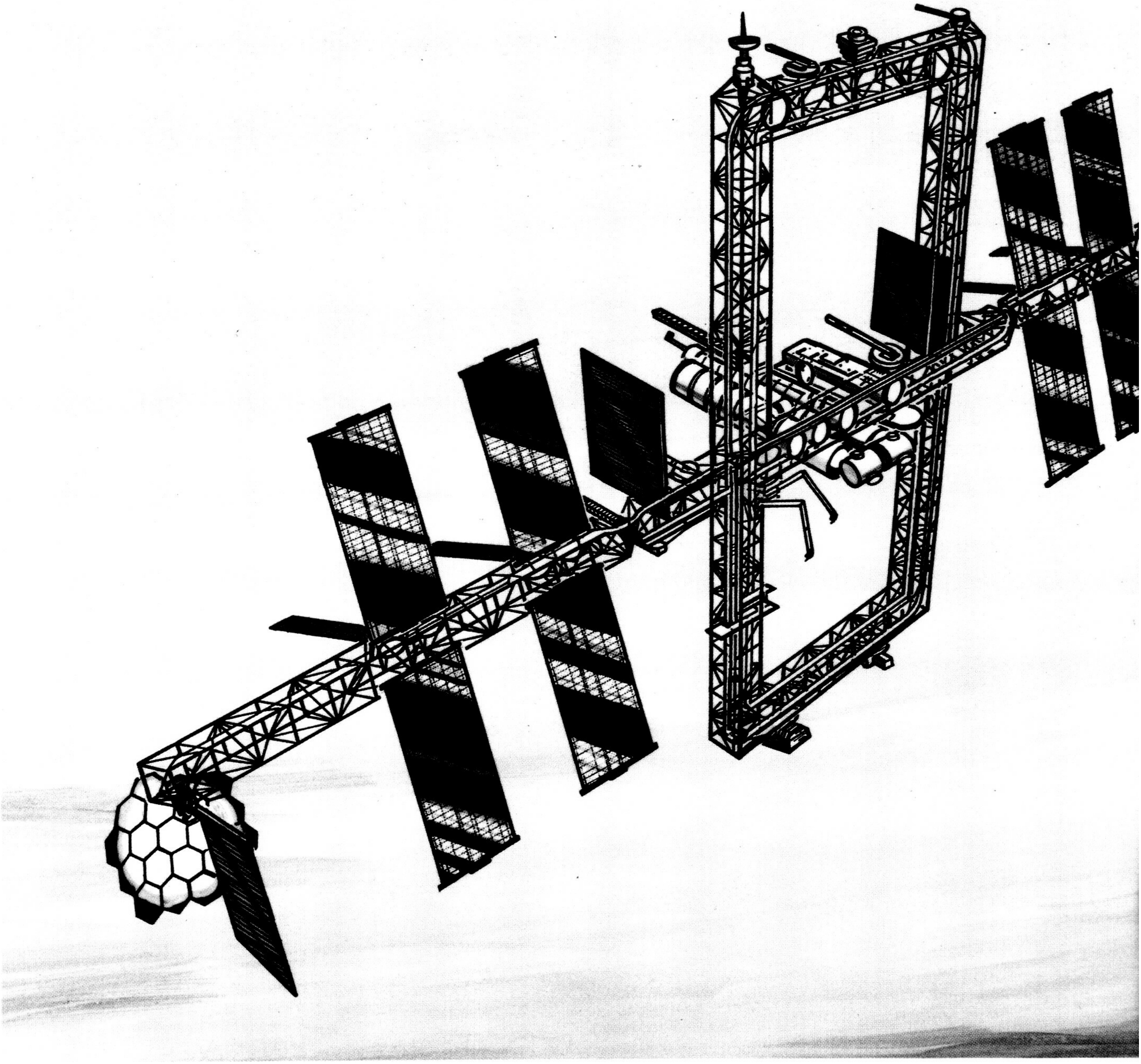


SPACE STATION FREEDOM

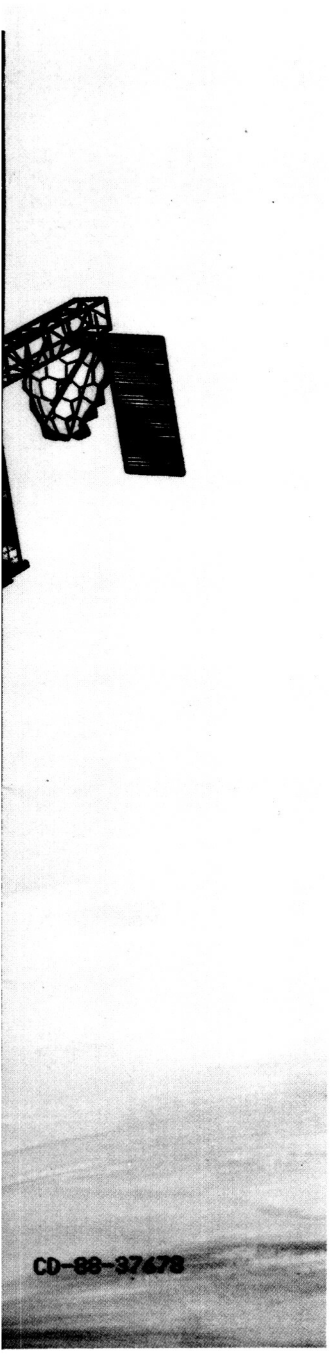
Space Station Freedom is an international endeavor. Freedom will consist of a manned base and three unmanned spacecraft. The manned base will be assembled in orbit beginning in early 1995. This will be accomplished by using the space shuttle to ferry components of Freedom into orbit.

The permanently manned base will orbit about every 90 minutes at are altitude of 220 miles above the Earth. During this orbit it will experience approximately 60 minutes of sunlight and 30 minutes of darkness due to an eclipse from the Earth.

The initial configuration of Freedom will have four pressurized modules attached to the center of a 360-foot boom. These modules will provide living and working quarters. Mounted on the end of each boom will be two photovoltaic power modules, each consisting of two solar array wings. Each array wing has two flexible blankets that are supported by a deployable/retractable mast. The array wings are approximately 30 feet wide by 108 feet long. The power system, during each orbit, will be capable of providing an average of 75 kilowatts of power with a peak of 100 kilowatts for 15 minutes. Electrical energy will be stored in nickel-hydrogen ($Ni\text{-}H_2$) batteries, which will be charged from the arrays during the sunlight portion of the orbit and discharged during the eclipse part, thus providing continuous power to the manned base.



Growth configuration of Freedom



Two free flying polar orbiting platforms (POP's), one built by the United States and one provided by the European Space Agency, are also included in the program. These platforms, which will be unmanned, will be used to house instruments, such as telescopes, that require a more stable environment. The European Space Agency will also provide a man-tended free flyer which will orbit with the station.

In the presently planned growth configuration, commonly referred to as Phase 2, dual keels (each approximately 340 ft long) will be added to the existing boom, and they will be joined by upper and lower booms; also, two solar dynamic (SD) power modules, one on each end of the original boom, will be added. Each SD module will be capable of adding 25 kilowatts of power. In addition, a U.S. co-orbiting platform (COP), which will orbit with the space station, will be included. A decision to proceed with Phase 2 may be made in the early 1990's.

S.S. Freedom will provide a microgravity environment for exploration in material and life sciences. Scientists will be able to produce defect-free crystals for computers, observe the effects of microgravity on living cells, study the Earth's atmosphere, and more.

LEWIS RESEARCH CENTER'S ROLE IN THE SPACE STATION FREEDOM PROGRAM

The Space Station Freedom Program is managed by NASA Headquarters in Washington, D.C.(commonly referred to as Level I). Program direction (Level II) is centered in Reston, Virginia, with implementation delegated to various NASA centers (Level III). Along with Lewis, these centers include Marshall Flight Center, Johnson Space Center, and Goddard Space Flight Center as hardware and software developers. The Kennedy Space Center provides ground operation support, and Langley Research Center supports technology development/evolutionary growth. In addition, the European Space Agency (ESA), Japan, and Canada are partners, each contributing hardware and software development to the Space Station Freedom Program.

Lewis' work package responsibility is the electric power system (EPS). Rocketdyne, a division of Rockwell International, has been awarded a contract to develop and build the EPS hardware and software. The EPS will consist of two types of power sources (photovoltaic power modules will be in the initial configuration and solar dynamic modules will be added in the growth configuration) and power management and distribution hardware (switchgear, microprocessor controls, and software). Once Freedom is completed and on-orbit, Lewis has the responsibility to support Freedom's EPS. Lewis' engineering support center will provide this on-orbit operations support.

POWER SYSTEMS FACILITY

The Power Systems Facility (PSF) was constructed for the development and on-orbit operating support of the S.S. Freedom electrical power system. The PSF is Lewis' newest facility, built at a cost of $6.2 million; it provides for a wide range of electrical power component and system testing.

The PSF has several areas with unique features. These areas include—the main test area, the Ni-H_2 energy storage room, and the test cell. The main test area is an 8300-square-foot high bay area with a 55-foot clearance below the 10-ton crane. This test area can operate as a class 100,000 clean room that is capable of removing 90 percent of the airborne particles. The Ni-H_2 energy storage room and the test cell are explosion-proof. They have interior walls and ceilings made of 12-inch reinforced concrete. Each room's exterior wall is designed as a blowout panel which will provide pressure release in the unlikely case of an explosion. These test cells are equipped with high-volume exhaust fans that are capable of completely changing the atmosphere in the cell in less than a minute.

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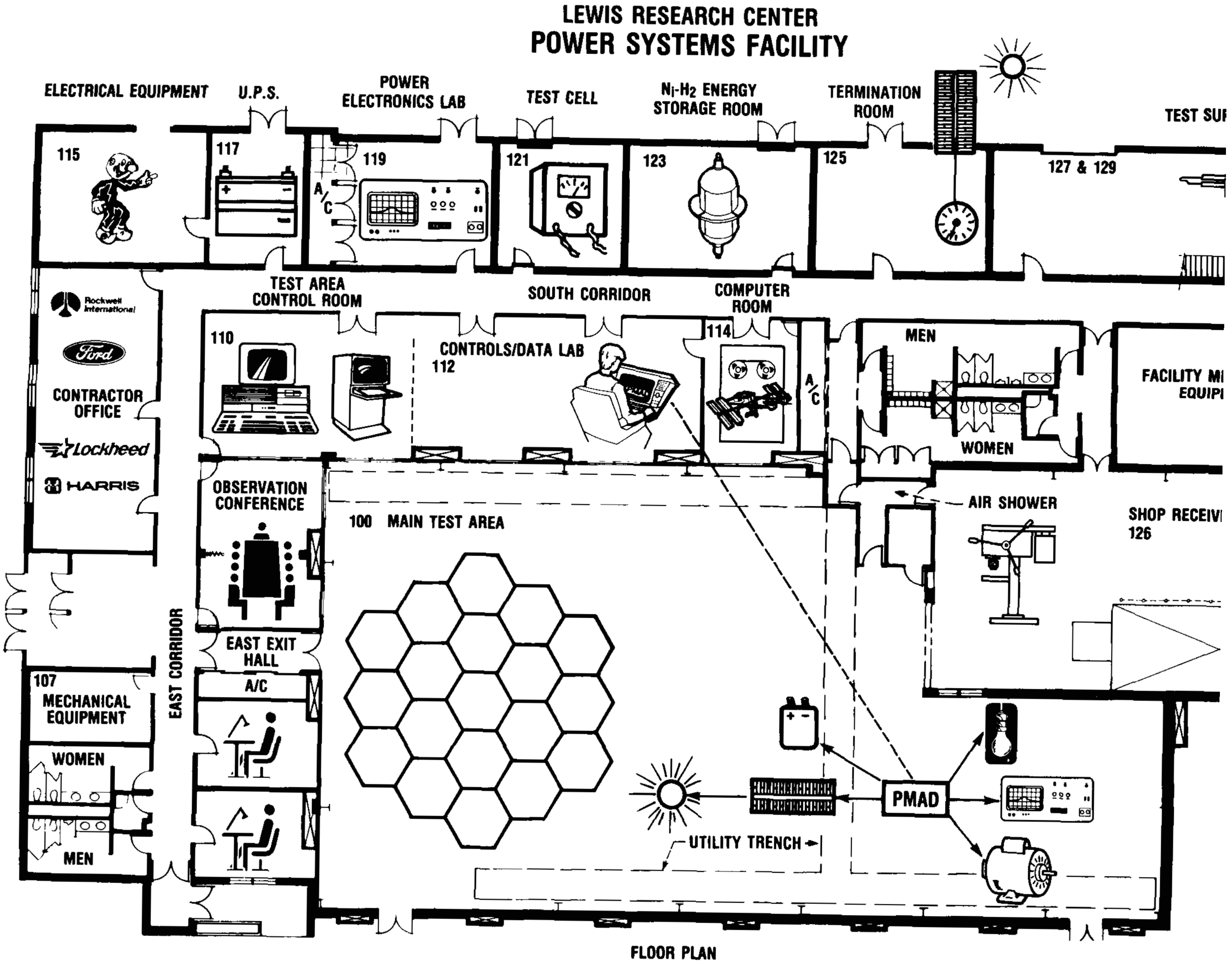
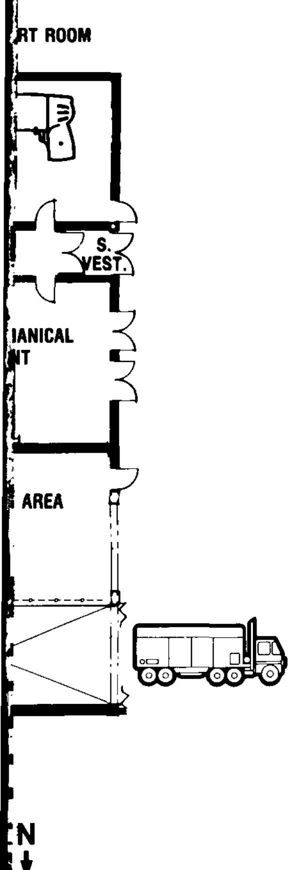


Utilization of the Power Systems Facility



The PSF utilizes an adjacent solar array field for power system and component testing. The solar array field consists of 960 silicon solar cell modules. The maximum array power is 30 kilowatts at 160 volts. The array field is tied to the facility through the termination room. The power produced by the array field is distributed from this room to other parts of the facility as required.

Hardware for the tests to be conducted in the PSF include Ni-H_2 batteries, solar concentrator mirror, and power management and distribution (PMAD) system and components. The PSF will include an engineering support center (ESC) to permit monitoring on-orbit power system performance. The ESC will have the capability of simulating any anomalies experienced in space for analysis and resolution.

UTILIZATION OF THE PSF

Room	*Room name*	*Utilization*
100	*Main test area*	*Permits testing to evaluate the electrical power system and its subsystems and optical testing of the solar concentrator mirror.*
110	*Test area control room*	*Is the control room for the main test area, a secondary control room for other test cells, and a distribution center for control signals.*
112	*Controls/data laboratory*	*Contains computers that simulate the electrical power system control and other S.S. Freedom system controls.*
114	*Computer room*	*Contains computers that simulate S.S. Freedom systems that interact with the power system being tested.*
117	*Uninterruptible power source (UPS) room*	*Contains an uninterruptible power source for clean, reliable power to the facility and the computers.*
119	*Power electronics laboratory*	*Contains equipment to accept, check, troubleshoot, and modify electrical power system components.*
121	*Test cell*	*Contains various equipment needed to test electrical power system components.*
123	*Ni-H_2 energy storage room*	*Permits life testing on Ni-H_2 batteries and battery packs.*
125	*Termination room*	*Interconnects the solar array power to the facility; solar array and battery simulators are also located here.*
126	*Shop/receiving*	*Serves as an unloading dock for delivered items and as a mechanical workshop; has the capability to become a pre-clean area for the main test area.*
127 and 129	*Test support room*	*Allows for the buildup of test support hardware.*

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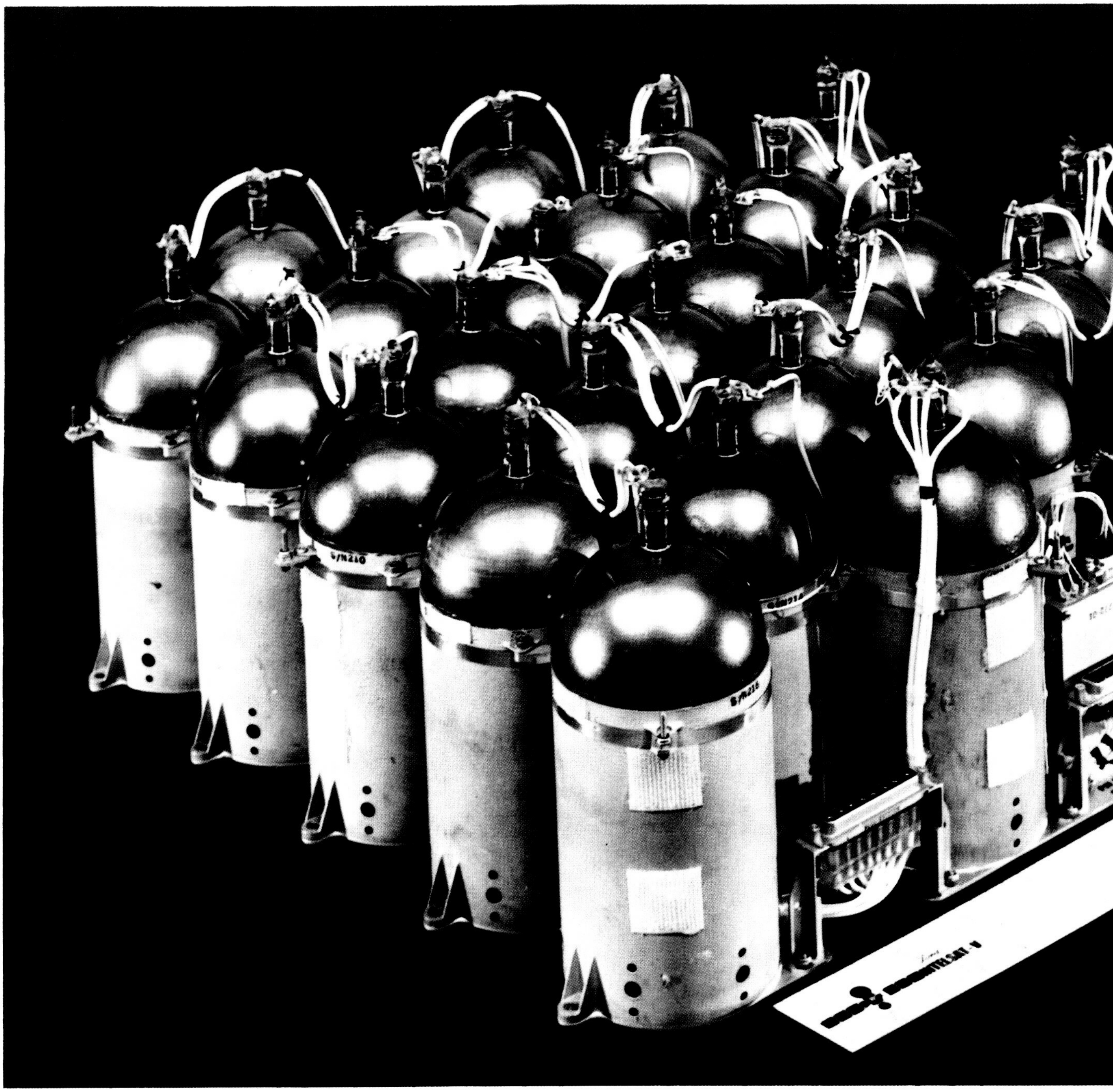

Ni-H_2 battery used on the Intelsat V satellite

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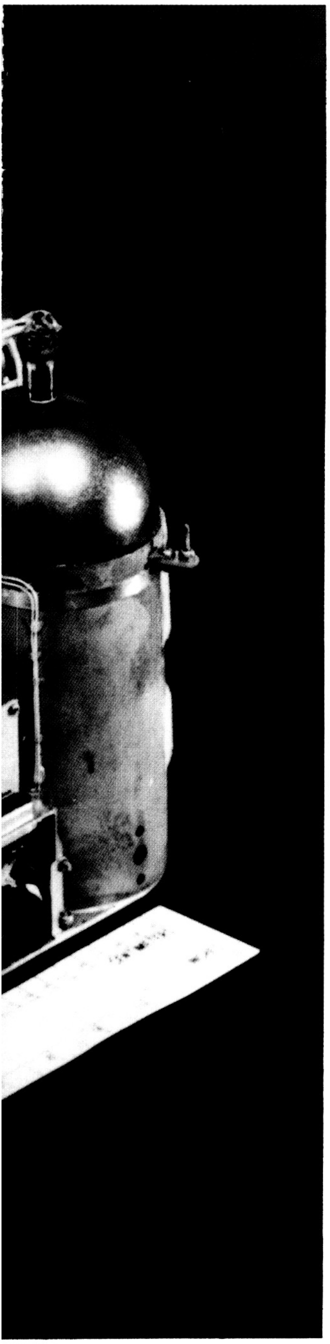

ENERGY STORAGE TESTING

Rocketdyne and Ford Aerospace Corporation are responsible for the testing program to qualify the selected Ni-H_2 battery design. A portion of this testing is to be conducted in the PSF's Ni-H_2 energy storage room. Individual pressure vessel (IPV) Ni-H_2 batteries were selected during the conceptual phase as the energy storage system for the manned base and U.S. co-orbiting platform and for the polar orbiting platform. The existing Ni-H_2 data base was developed for geosynchronous satellites orbiting at 22,000 miles, experiencing 90 sunlight/eclipse cycles per year; Freedom, however, will orbit at 220 miles, experiencing nearly 6,000 sunlight/eclipse cycles per year. Since this high cyclic life is much more stressful to a Ni-H_2 cell, long life and performance must be proven; therefore, cyclic life testing of IPV Ni-H_2 cells and batteries will be conducted to demonstrate that the designs exceed the life and performance goals of 5 years of continuous operation.

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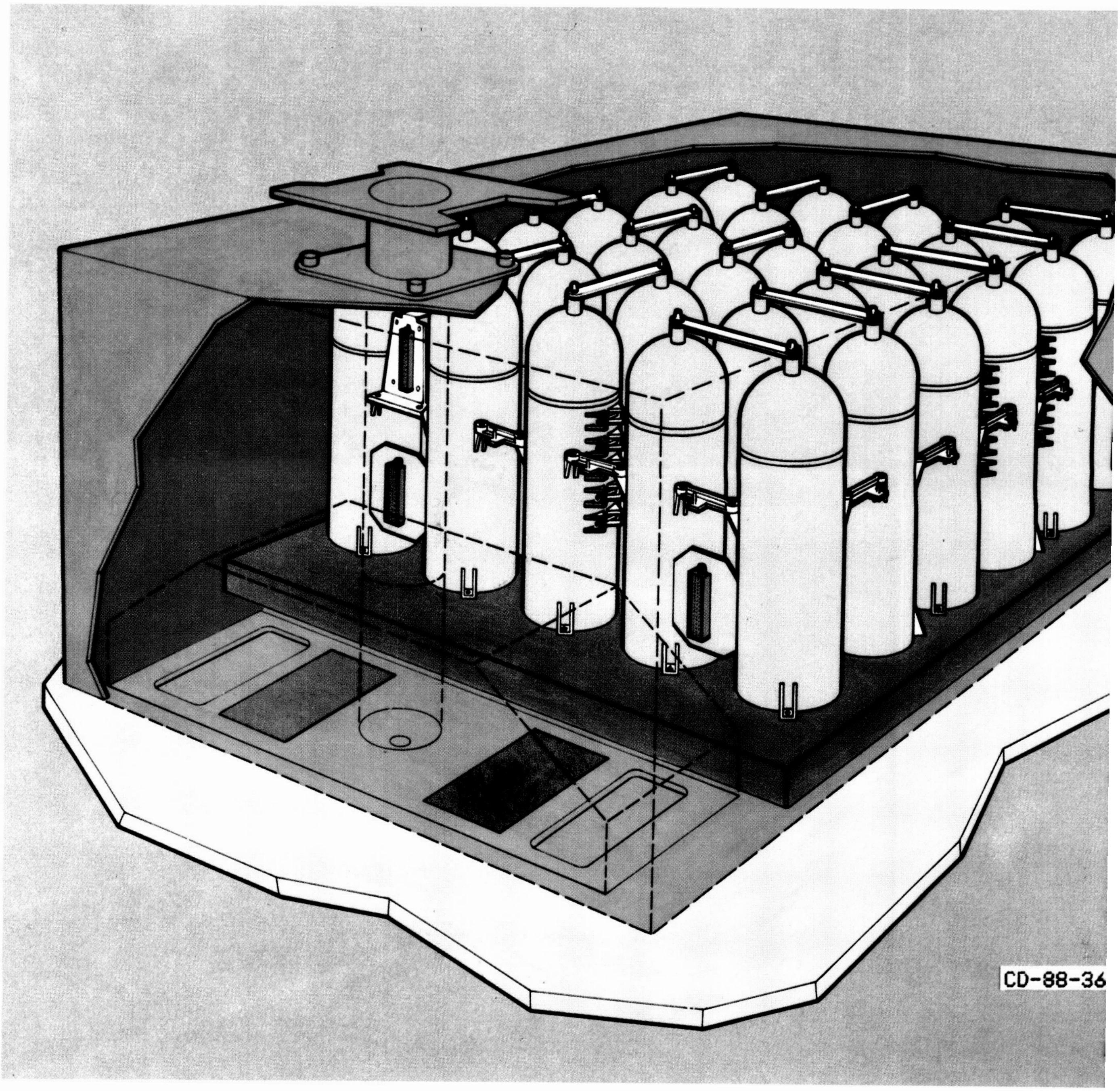
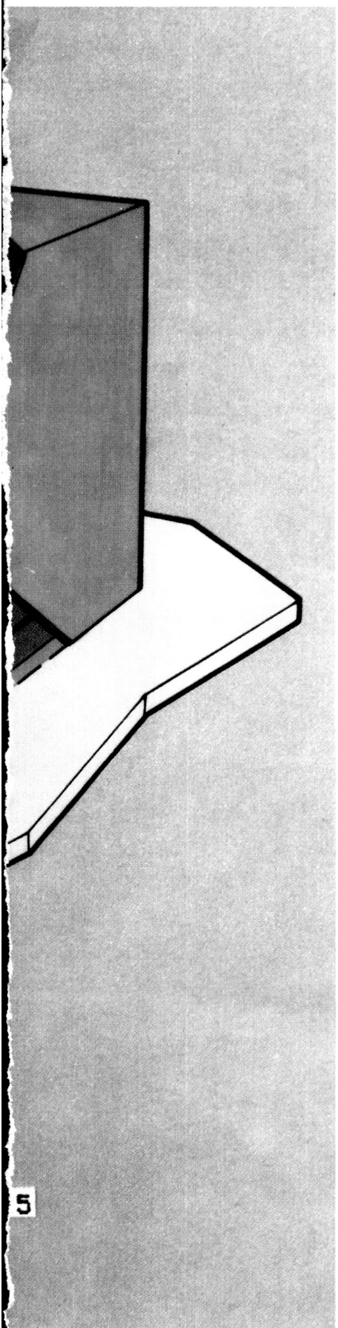


Ni-H_2 energy storage orbital replacement unit



The initial tests in the PSF focus on a development level energy storage orbital replacement unit (ORU), which consists of 30 IPV $Ni\text{-}H_2$ cells electrically connected in series. The design is similar to the $Ni\text{-}H_2$ battery employed on the Intelsat V satellite.

Testing at this level verifies series connected cell operation, determines the optimum method to recharge the batteries, and defines the battery handling/operation procedures. Later, integrated testing of ORU's will be conducted at the flight hardware prototype level. Three ORU's are connected in series along with a battery charge/discharge unit (BCDU) to control battery cycling. Battery/BCDU integrated tests demonstrate proper load sharing between batteries, verify thermal control of the components, and assist in diagnosing on-orbit anomalies. All the $Ni\text{-}H_2$ battery tests are life tests and will be cycled until failure to verify NASA's goal of 5-year life for the batteries.

POWER MANAGEMENT AND DISTRIBUTION TESTING

The power management and distribution (PMAD) system insures that all the components of the electrical power system work in concert to provide safe and reliable electrical power to all the consumers. The 20-kilohertz single-phase utility quality power is provided through as many as four redundant paths. Each of these independent paths has microprocessor-controlled switches to protect it against the undesirable effects of overloads on the users as well as on the power system.

The PMAD controls system contains microprocessor-based controllers located in key components and interlinked by redundant control data busses. These controllers operate with the redundant power management controllers (PMC) to control the electrical power system, measure its performance and status, and provide essential information to the crew and ground controllers. The control software within the controllers is based on proven techniques currently used in terrestrial power systems. This control system will provide Freedom with a fully automated power management capability.

TEST BEDS IN PSF

The PSF houses a number of specialized test beds. These test beds support the full power system tests by verifying critical system concepts, testing hardware in very early stages of development, and identifying and resolving areas of concern in testing prior to the end-to-end tests. The initial planned test bed activity includes two key installations—the integrated test bed (ITB) and the test bed support laboratory.

The ITB emulates all the functions of the power systems major components and assemblies. It integrates each component of the PMAD system with EPS system simulators to form a functional system; however, it differs from the proposed flight end-to-end configuration because early developmental models of the components will be used and only a representative user load is utilized. This ITB is especially useful in trying out new components and operating concepts in a system environment early in the program.

The core of the test bed support laboratory is a high-speed computer capable of running simulations in real time. This simulator interfaces with power systems controllers, graphics work stations, and a host minicomputer. This test bed support laboratory allows control concepts and control software to be tested in an environment in which all the essential functions of the hardware are simulated, and it affords an opportunity to test software in very early stages of development.

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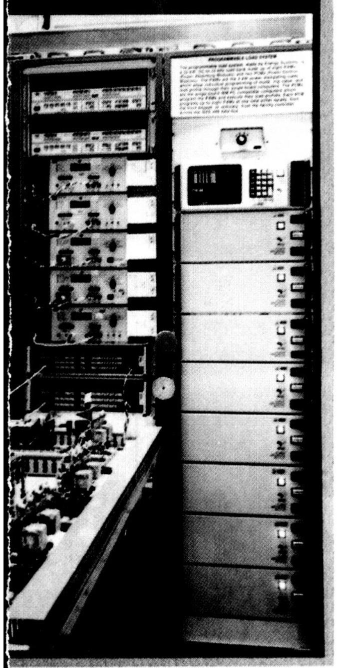
Electrical power system testing



It also provides the capability to test control concepts in situations in which the hardware functions are outside normal limits without concern for damaging hardware. Because this laboratory will eventually include multipurpose control consoles, which will be the same control consoles as on Freedom, it will also provide a training facility for Freedom personnel.

ROLE OF PSF IN SYSTEM TESTING

To assure that the components will operate together on-orbit as a system, the PSF is used for intermediate and end-to-end manned base electrical system tests. The electrical system integrated tests (ESIT) are performed using a combination of development hardware, prototype software, flight software, and high-fidelity simulators. The PSF is particularly suited to this type of testing because of its capability for testing a complete system including full-sized hardware, simulated or real loads, and distributed controls.

The manned base will be launched in segments because of its size. After each launch, the EPS will have a new configuration closer to the complete configuration. ESIT will verify that these intermediate configurations and the final one perform as expected.

As Freedom grows, the end-to-end test configuration in the PSF will be expanded by adding additional PMAD hardware and software and the solar dynamic (SD) power module simulator. All new functions and additional interfaces will be tested.

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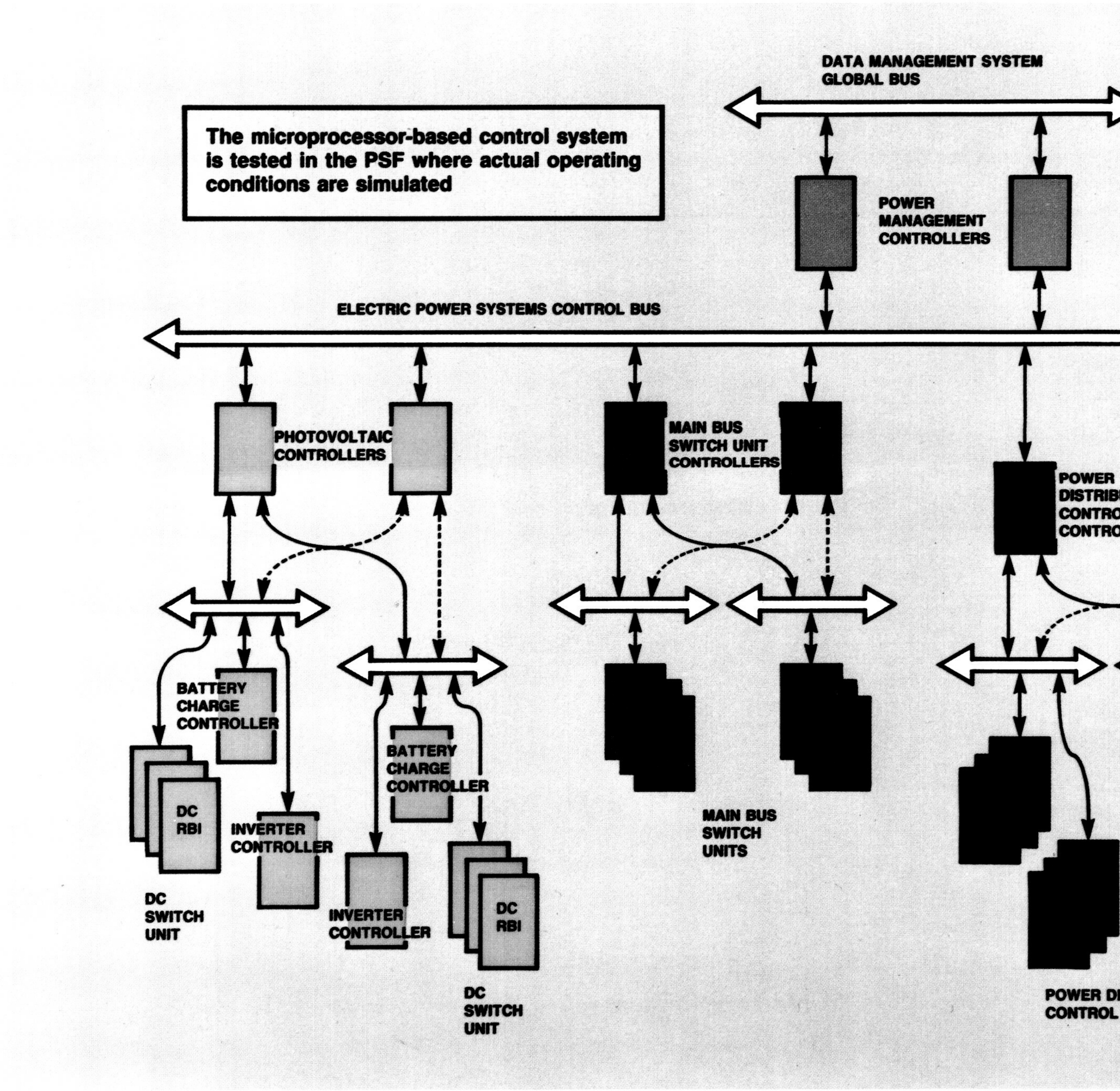
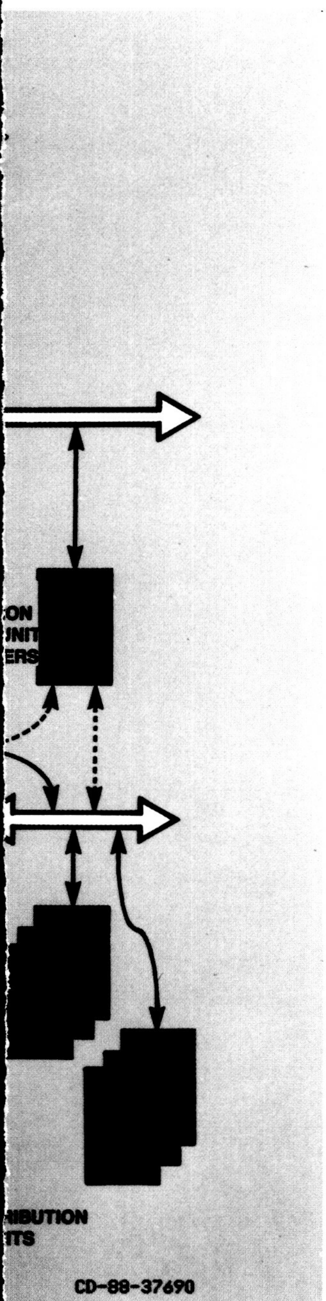


Electrical power system control architecture



PMAD SOFTWARE

PMAD software provides the detailed procedures for the control system to perform the functions crucial to safe, efficient operation of the electrical power system. It is a highly complex system in that the software is distributed throughout the PMAD system. Each controller contains the appropriate software to enable it to carry out its unique responsibility.

The PSF plays a key role in testing to ensure that the software meets all the operational requirements. In particular, the PSF is the only place where all the individual controllers, each with its specialized software, are tested as a functioning system before Freedom is assembled in space. This final integration and validation testing of the flight software will be carried out in the PSF as the final step in a planned series of tests that began at the contractor's plant.

IMPORTANCE OF SYSTEM TESTING TO THE S.S. FREEDOM PROGRAM

System validation will be performed in both NASA Lewis and contractor facilities to insure that the electrical power system performs its proper functions and operates in a manner that is safe for the space station crew. The combination of environmental testing of PMAD components together with the full-system functionality tests at the PSF will insure that a fully operational electrical power system is qualified for Space Station Freedom.

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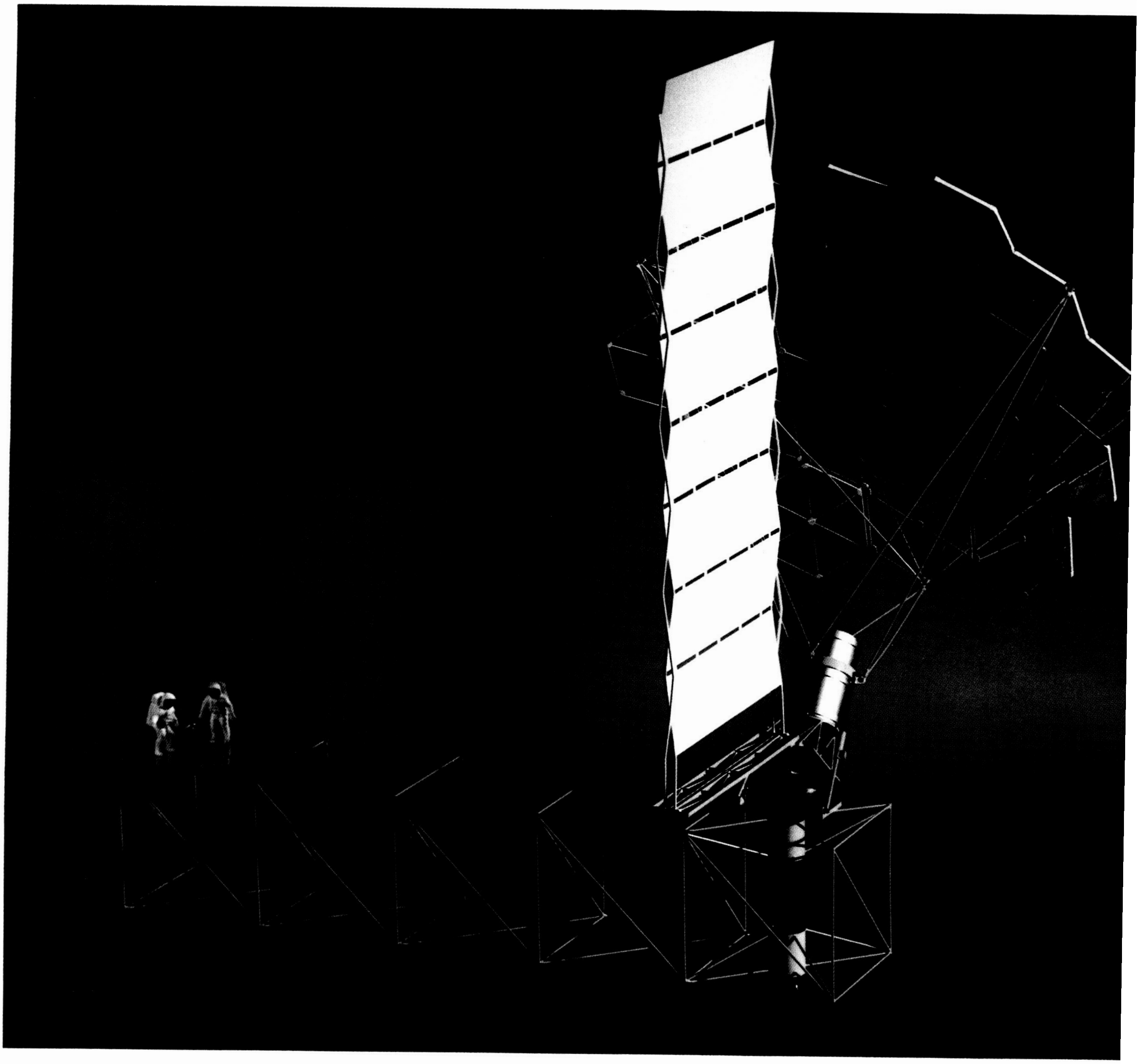
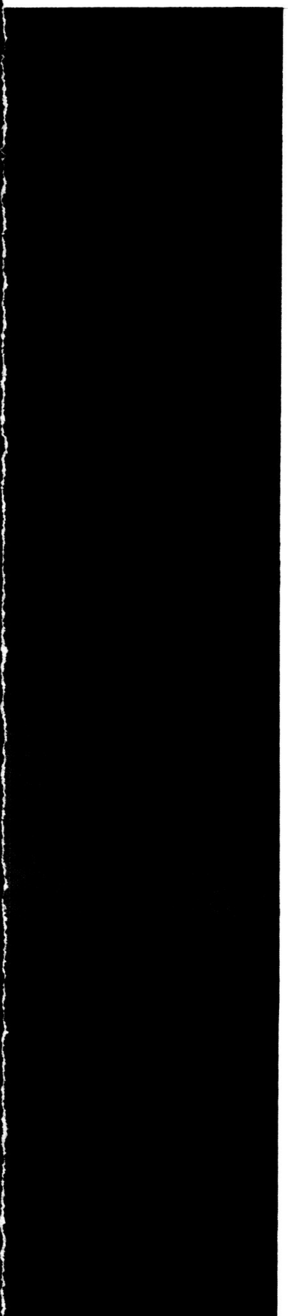


Solar dynamic power module



SOLAR DYNAMIC TESTING

One of the critical elements of the 25-kilowatt solar dynamic power module is the solar concentrator mirror. The Solar Concentrator Advanced Development (SCAD) Project was initiated in 1985 with the objective of developing and demonstrating key solar concentrator technologies that are required for space station applications. Under the SCAD contract with NASA Lewis, the Harris Corporation designed and built a prototype solar concentrator very similar to the proposed flight concentrator design. The SCAD concentrator consists of 19 graphite epoxy panels with each panel housing 24 triangular reflective facets. The overall diameter of the concentrator in its assembled form is approximately 60 feet.

The SCAD concentrator is tested in the PSF main test area. The main objective of the tests is to determine the overall optical characteristics of the concentrator; a secondary objective is to validate and verify the performance of two optical measurement systems.

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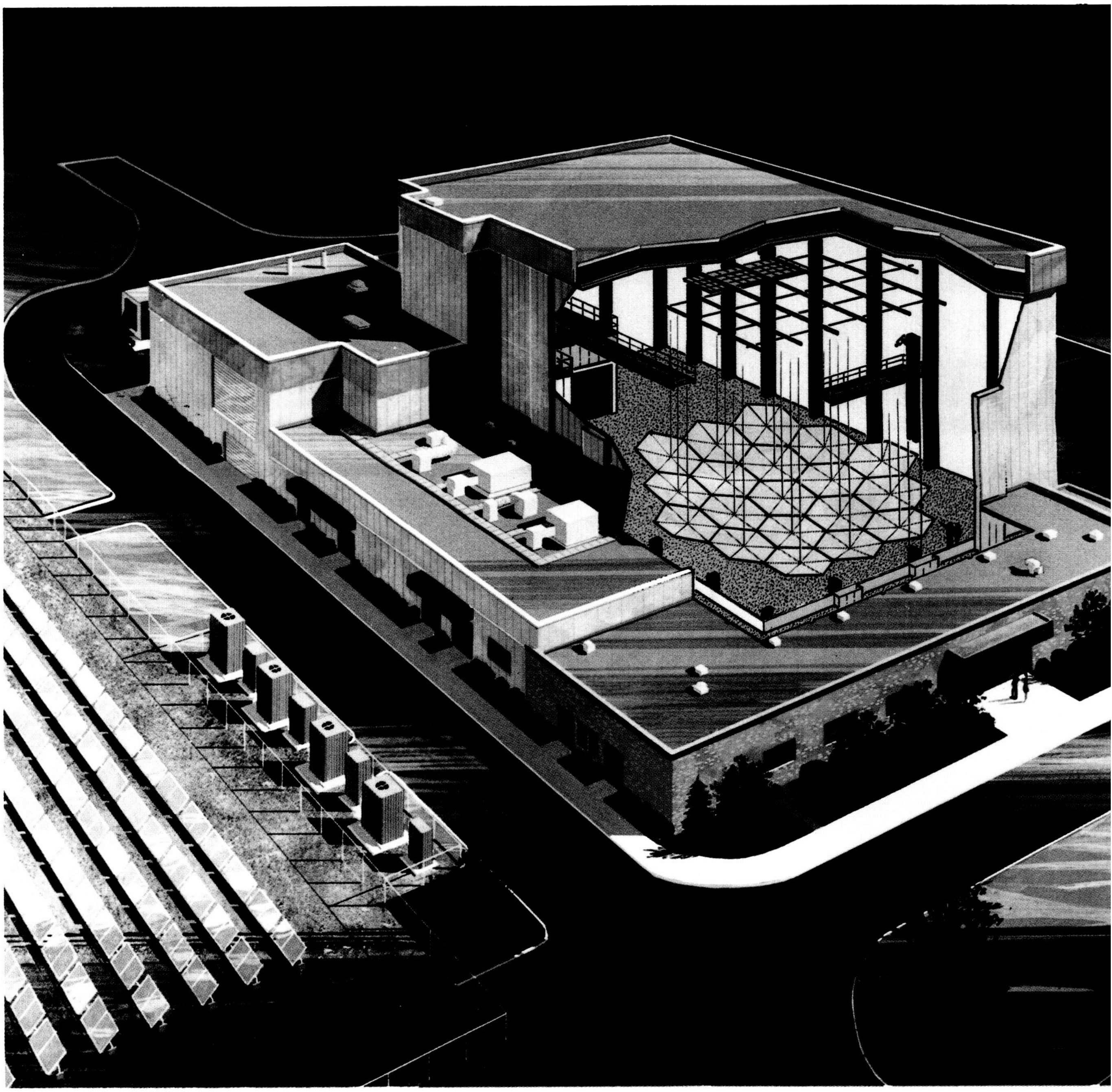


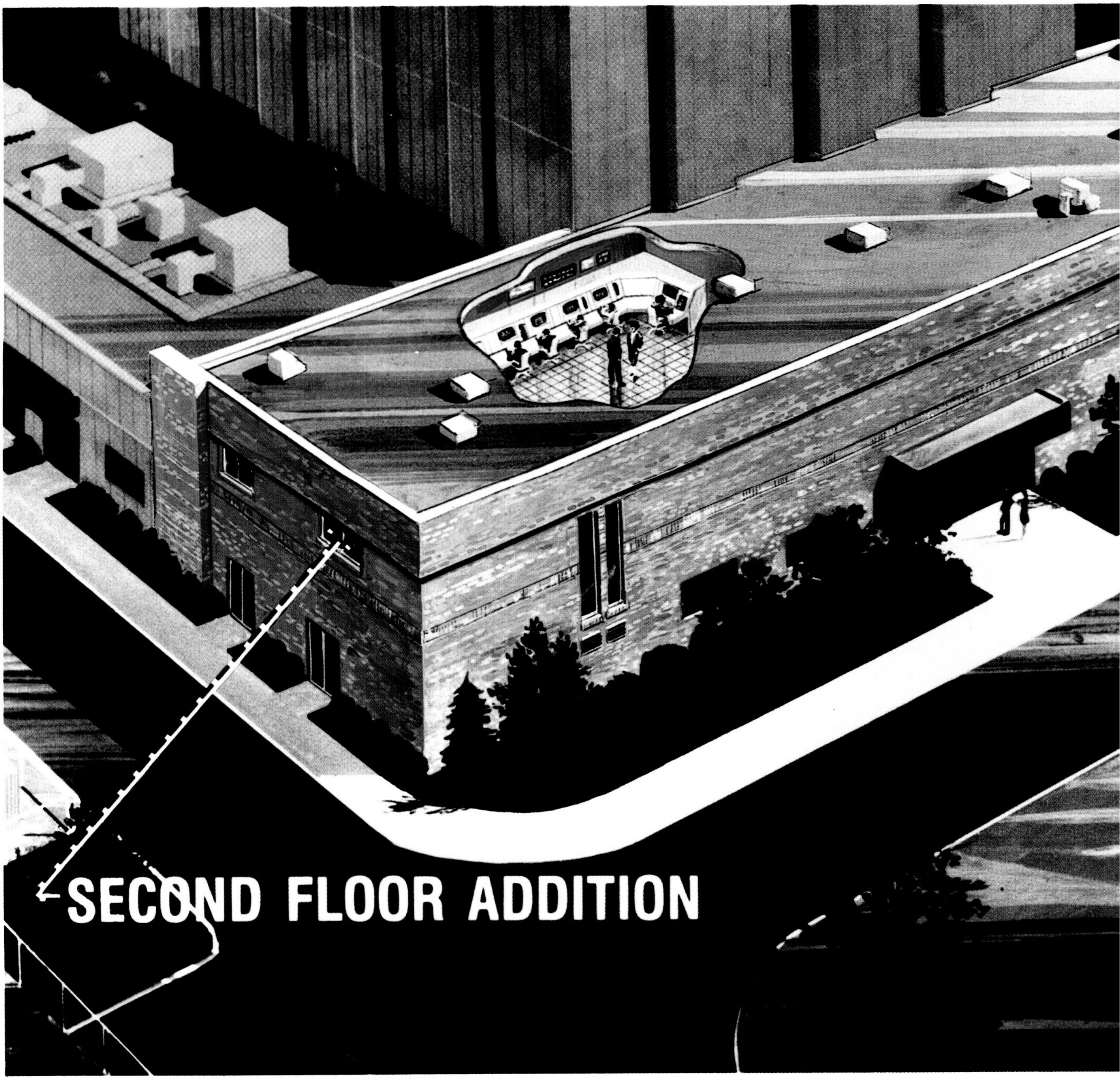
Solar concentrator testing

The first series of tests evaluates geometry of the structure and facet orientation. These tests are being conducted by the Harris Corporation as part of the SCAD Project. Harris will first determine the ability of the panels to repeat their positions after several assembly and disassembly sequences. Once that portion of the testing is completed, reflective facets will be installed in the panels for the optical testing. Using a laser scanning system, Harris will direct the laser beam at the center of each facet and measure where the reflected beam strikes the focal plane. The data from these tests will be used to determine the optical characteristics of the concentrator.

The second series of optical tests in the PSF will use a Digital Imaging Radiometer (DIR) measurement system. This system, designed and built by the McDonnell Douglas Corporation, is different from the laser scanning system in that it can characterize the total concentrator optical performance in one test run. Hundreds of individual lights are turned on and off very rapidly in grouped sequences with each group of lights corresponding to individual reflective facets. A receiving camera picks up the light reflected from the facets and feeds the data to a computer for processing. The computer then calculates the measured optical performance of the concentrator.

The expected outcome of these tests are as follows:

1. Concentrator design will be verified and validated, and vital input for the Freedom flight concentrator design will be provided.
2. Computer optical codes will be validated when the test results are compared to the predictions.
3. Overall performance of the optical measurement systems will be verified.



Engineering support center

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FUTURE S.S. FREEDOM OPERATIONS SUPPORT

The manned base of S.S. Freedom is expected to remain in orbit and operate for an indefinite time. While the manned base is in orbit, the performance and maintenance of the electric power system will be vital to a successful mission. The Freedom Program has specified that each responsible NASA center must provide ground support to its respective system while Freedom is in orbit. Lewis will accomplish this by providing an engineering support center (ESC). In addition, the Lewis ESC will support the electric power systems on the polar-orbiting platform. The heart of the ESC will be its central data and voice system (CDVS). Through the space station information system (SSIS) interface, the CDVS will be able to receive and transmit digital scientific and operations data, video, and voice signals in support of Freedom's operations. CDVS will distribute these signals to as many as 40 operations support and work station consoles within the ESC and elsewhere at Lewis allowing personnel to support a wide variety of activities. Among these activities are the following:

- Ground processing of EPS hardware and verification of its health and readiness before it is launched
- Mission operations support from prelaunch of EPS hardware through sustaining operations over the life of Freedom
- Ground support to assist in solving EPS on-orbit problems
- Operations support of routine long-term Freedom operations
- Training and certification of ESC operating personnel, other ground support personnel, and flight crews

Since the ESC will be housed in a proposed second floor addition to the office wing of the PSF, it will have the advantage of being able to use adjacent EPS development components and subsystems to assist in solving EPS operating problems during the lifetime of S.S. Freedom.

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15. Supplementary Notes

16. Abstract

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